

**TRANSIMPEDANCE AMPLIFIER
WITH CONTROLLABLE NOISE REDUCTION**

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0001] The present invention relates to amplifiers for amplifying signals having low magnitudes, and in particular, to transimpedance amplifiers used for amplifying signals having low magnitudes and containing DC offsets.

2. Description of the Related Art

[0002] Optical receivers responsible for receiving and amplifying data signals generated by optical signal systems typically use transimpedance amplifiers to receive and amplify the current based signal provided by a photodiode that receives the actual optical signal transmission. Such signals typically include a DC component, which often requires compensation so as to prevent biasing problems within the amplifier.

[0003] Referring to Figure 1, a conventional transimpedance amplifier circuit for performing this function includes a gain stage in the form of an amplifier A1 (e.g., an operational amplifier) with a feedback resistor R2 between the input 3 and output 5 terminals. Also connected to the input terminal 3 is a current source I1 which provides a compensation circuit Ic (discussed in more detail below). The output signal voltage Vout also drives a lowpass filter circuit in the form of a serially connected resistance R1 and capacitance C1. The voltage V1 (which is the DC component of the output signal Vout) across the capacitor C1 is compared in a voltage comparison circuit A2 (e.g., voltage comparator) with a reference

voltage V_{ref} . The resulting signal V_2 from this voltage comparison circuit A2 controls the current source I1, thereby controlling the compensation current I_c .

[0004] The photodiode D1 provides a signal current I_s to the input node mutually connecting the current source I1, feedback resistor R2 and amplifier input terminal 3. When no light 1 is impinging upon the photodiode D1, the diode current I_s is zero. During impingement of light 1 upon the photodiode D1, the diode current I_s is non-zero and has a value determined by the responsivity of the photodiode and the input light power. If the incoming light signal 1 represents a data signal having a substantially equal number of ones and zeros, then the average photodiode current I_{sa} will be equal to one-half of the peak photodiode current I_{s1} occurring during reception of a signal corresponding to a logical 1 ($I_{sa} = I_{s1}/2$). This average I_{sa} current flows through the feedback resistor R2 of the transimpedance amplifier 4, thereby producing a potential difference between the DC bias points of the input terminal 3 and output terminal 5 of the amplifier A1. Accordingly, the DC bias point of the amplifier output terminal 5 is now dependent upon, i.e., varies with, the magnitude of the incoming signal, i.e., photodiode current I_s , thereby making it difficult to maintain the DC biasing of the amplifier A1 for maximum dynamic range.

[0005] The conventional solution for this has been to provide the variable current source I1 at the input terminal 3 of the amplifier A1. The compensation current I_c provided by this current source I1 removes the DC component of the photodiode current I_s . This is achieved by comparing the DC component V_1 of the output signal voltage V_{out} (by lowpass filtering the output signal voltage V_{out}) with the reference voltage V_{ref} . If the DC output signal component V_1 differs from the desired DC bias level, as represented by the reference voltage V_{ref} , such voltage difference is caused by the DC component of the photodiode current I_s

flowing through the feedback resistor R2. Accordingly, the output signal V2 from the voltage comparison circuit A2 controls the current source I1 such that the compensation current Ic compensates for, i.e., removes, the DC component of the photodiode current Is at the amplifier input terminal 3, thereby causing the DC level at the amplifier output terminal 5 to return to and remain at the desired biasing point.

[0006] This conventional approach, however, is less than satisfactory for low values of photodiode current Is. As is well known, the current source I1 introduces thermal noise at the input node. The noise current resulting from such thermal noise is approximately equal to $4\alpha KT G_m$ for metal oxide semiconductor devices (where α is a technology-dependent MOSFET parameter which is typically approximately 2/3, K is Boltzmann's constant, T is temperature in degrees Kelvin, G_m is the transconductance of the current source I1) and $2QI_c$ for bipolar junction transistors (where Q is the charge of an electron (1.6×10^{-19}) and I_c is the compensation current). In low signal noise applications, i.e., where the photodiode current Is contains little signal noise, this thermal noise is the dominant noise source and degrades the signal-to-noise ratio (SNR), thereby causing an increased bit error rate (BER).

SUMMARY OF THE INVENTION

[0007] In accordance with the presently claimed invention, a transimpedance amplifier with controllable noise reduction is provided in which DC offsets due to the input signal are tolerated during reception of low input signals by reducing, e.g., terminating, a compensation current to remove a dominant source of thermal noise, but compensated during reception of higher input signals where the effects of DC offsets are more dominant.

[0008] In accordance with one embodiment of the presently claimed invention, a transimpedance amplifier with controllable noise reduction includes amplifier circuitry and control circuitry. The amplifier circuitry includes input and output terminals, and is responsive to reception of an input signal and a compensation signal via the input terminal by providing an output signal via the output terminal, wherein: the input signal includes an AC component and a DC component; the compensation signal includes a DC component inverse in polarity to the input signal DC component; and the output signal includes an AC component corresponding to the input signal AC component, and a DC component comprising a sum of first and second DC subcomponents, wherein the first DC subcomponent corresponds to the input signal DC component. The control circuitry is coupled to the amplifier circuitry input and output terminals, and is responsive to reception of the output signal DC component and a reference signal including a DC component by providing the compensation signal, wherein: the reference signal DC component comprises a sum of third and fourth DC subcomponents; the third DC subcomponent corresponds to the second DC subcomponent; and the compensation signal DC component corresponds to a difference between the first and fourth DC subcomponents.

[0009] In accordance with another embodiment of the presently claimed invention, a transimpedance amplifier with controllable noise reduction includes amplifier means and controller means. The amplifier means is for receiving an input signal and a compensation signal and in response thereto generating an output signal, wherein: the input signal includes an AC component and a DC component; the compensation signal includes a DC component inverse in polarity to the input signal DC component; and the output signal includes an AC component corresponding to the input signal AC component, and a DC component

comprising a sum of first and second DC subcomponents, wherein the first DC subcomponent corresponds to the input signal DC component. The controller means is for receiving the output signal DC component and a reference signal including a DC component and in response thereto generating the compensation signal, wherein: the reference signal DC component comprises a sum of third and fourth DC subcomponents; the third DC subcomponent corresponds to the second DC subcomponent; and the compensation signal DC component corresponds to a difference between the first and fourth DC subcomponents.

[0010] In accordance with another embodiment of the presently claimed invention, a transimpedance amplifier with controllable noise reduction includes input, output and reference terminals, amplifier circuitry and signal generator circuitry. The input terminal is to convey an input signal and a compensation signal, wherein: the input signal includes an AC component and a DC component; and the compensation signal includes a DC component inverse in polarity to the input signal DC component. The output terminal is to convey an output signal which includes an AC component corresponding to the input signal AC component, and a DC component comprising a sum of first and second DC subcomponents, wherein the first DC subcomponent corresponds to the input signal DC component. The reference terminal is to convey a reference signal including a DC component corresponding to a sum of the second DC subcomponent and a DC offset. First amplifier circuitry is coupled to the input and output terminals, and is responsive to reception of the input and compensation signals by providing the output signal. Second amplifier circuitry is coupled to the output and reference terminals, and is responsive to reception of the output signal DC component and the reference signal by providing a control signal with a value related to a difference between the first DC subcomponent and the DC offset. The signal generator

circuitry is coupled to the input terminal and the second amplifier circuitry, and is responsive to reception of the control signal by providing the compensation signal.

[0011] In accordance with another embodiment of the presently claimed invention, a transimpedance amplifier with controllable noise reduction includes amplifier means and signal generator means. First amplifier means is for receiving an input signal and a compensation signal and in response thereto generating an output signal, wherein: the input signal includes an AC component and a DC component; the compensation signal includes a DC component inverse in polarity to the input signal DC component; the output signal includes an AC component corresponding to the input signal AC component, and a DC component comprising a sum of first and second DC subcomponents; and the first DC subcomponent corresponds to the input signal DC component. Second amplifier means is for receiving the output signal DC component and a reference signal and in response thereto generating a control signal, wherein: the reference signal includes a DC component corresponding to a sum of the second DC subcomponent and a DC offset; and the control signal has a value related to a difference between the first DC subcomponent and the DC offset. The signal generator means is for receiving the control signal and in response thereto generating the compensation signal.

[0012] In accordance with another embodiment of the presently claimed invention, a transimpedance amplifier with controllable noise reduction includes input, output and reference terminals, amplifier circuitry and signal generator circuitry. The input terminal is to convey an input signal and a compensation signal, wherein: the input signal includes an AC component and a DC component; and the compensation signal includes a DC component inverse in polarity to the input signal DC component. The output terminal is to convey an

output signal which includes an AC component corresponding to the input signal AC component, and a DC component comprising a sum of first and second DC subcomponents, wherein the first DC subcomponent corresponds to the input signal DC component. The reference terminal is to convey a reference signal including a DC component corresponding to a sum of the second DC subcomponent and a DC offset. First amplifier circuitry is coupled to the input and output terminals, and is responsive to reception of the input and compensation signals by providing the output signal. Second amplifier circuitry is coupled to the output and reference terminals, and is responsive to reception of the output signal DC component and the reference signal by providing a control signal. The signal generator circuitry is coupled to the input terminal and the second amplifier circuitry, and is responsive to reception of the control signal by providing the compensation signal, wherein the compensation signal DC component corresponds to a difference between the first DC subcomponent and the DC offset.

[0013] In accordance with another embodiment of the presently claimed invention, a transimpedance amplifier with controllable noise reduction includes amplifier means and signal generator means. First amplifier means is for receiving an input signal and a compensation signal and in response thereto generating an output signal, wherein: the input signal includes an AC component and a DC component; the compensation signal includes a DC component inverse in polarity to the input signal DC component; the output signal includes an AC component corresponding to the input signal AC component, and a DC component comprising a sum of first and second DC subcomponents; and the first DC subcomponent corresponds to the input signal DC component. Second amplifier means is for receiving the output signal DC component and a reference signal and in response thereto

generating a control signal, wherein the reference signal includes a DC component corresponding to a sum of the second DC subcomponent and a DC offset. The signal generator means is for receiving the control signal and in response thereto generating the compensation signal, wherein the compensation signal DC component corresponds to a difference between the first DC subcomponent and the DC offset.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] Figure 1 is a circuit schematic of a conventional transimpedance amplifier circuit for input signals having low magnitudes.

[0015] Figure 2 is a circuit schematic of a transimpedance amplifier with controllable noise reduction in accordance with one embodiment of the presently claimed invention.

[0016] Figure 2A is a schematic diagram of one possible embodiment of the current source of Figure 2.

[0017] Figure 3 is a circuit schematic of a transimpedance amplifier with controllable noise reduction in accordance with another embodiment of the presently claimed invention.

[0018] Figure 3A is a schematic diagram of one possible embodiment of the current source of Figure 3.

[0019] Figure 4 is a circuit schematic of a replica voltage generator suitable for use with the circuits of Figures 2 and 3.

DETAILED DESCRIPTION OF THE INVENTION

[0020] The following detailed description is of example embodiments of the presently claimed invention with references to the accompanying drawings. Such description is

intended to be illustrative and not limiting with respect to the scope of the present invention. Such embodiments are described in sufficient detail to enable one of ordinary skill in the art to practice the subject invention, and it will be understood that other embodiments may be practiced with some variations without departing from the spirit or scope of the subject invention.

[0021] Throughout the present disclosure, absent a clear indication to the contrary from the context, it will be understood that individual circuit elements as described may be singular or plural in number. For example, the terms “circuit” and “circuitry” may include either a single component or a plurality of components, which are either active and/or passive and are connected or otherwise coupled together (e.g., as one or more integrated circuit chips) to provide the described function. Additionally, the term “signal” may refer to one or more currents, one or more voltages, or a data signal. Within the drawings, like or related elements will have like or related alpha, numeric or alphanumeric designators.

[0022] Referring to Figure 2, a transimpedance amplifier with controllable noise reduction in accordance with one embodiment of the presently claimed invention includes a transimpedance amplifier 4, voltage comparison circuit A2 and current source I1, as discussed above, but provides for comparison of the DC component V1 of the output signal voltage Vout with a different threshold voltage which is a sum of the reference voltage Vref (corresponding to the desired DC bias point for the amplifier output terminal 5) and an offset voltage Voff.

[0023] The offset voltage Voff is ideally selected to be the minimum of: the maximum tolerable signal excursion, i.e., peak magnitude of the AC component, of the output voltage Vout at the amplifier output terminal 5; and the minimum voltage Vr2min across the

feedback resistor R2 at which the value of the photodiode current I_s is large enough to achieve the desired BER notwithstanding thermal noise due to the compensation current I_c . Preferably, the amplifier A1 is designed to have sufficient gain such that such a minimum voltage V_{r2min} across the feedback resistor R2 is less than the maximum tolerable signal excursion at the amplifier output terminal 5. Accordingly, the offset voltage V_{off} is set equal to such minimum feedback resistor voltage V_{r2min} .

[0024] At low signal amplitudes, i.e., where the incoming photodiode current I_s produces a voltage V_{r2} across the feedback resistor R2 which is less than the minimum feedback resistor voltage V_{r2min} discussed above, the DC voltage V_{r2} across the feedback resistor R2 is less than the offset voltage V_{off} . Hence, with this voltage V_{r2} summed with the nominal DC biasing component at the amplifier output terminal 5, the total DC component V_1 of the output signal voltage V_{out} is less than the threshold voltage of $V_{ref}-V_{off}$. Accordingly, the output V_2 of the voltage comparison circuit A2 goes low and the current source I1 is turned off. Hence, with no compensation current I_c drawn from the input node, no thermal noise is added by the current source I1.

[0025] At larger amplitudes where the DC component of the photodiode current I_s produces a voltage V_{r2} across the feedback resistor R2 which is greater than the minimum feedback resistor voltage V_{r2min} discussed above, the DC voltage V_{r2} across the feedback resistor R2 is greater than the offset voltage V_{off} . As a result, the DC component V_1 of the output voltage V_{out} at the amplifier output terminal 5 is greater than the threshold voltage of $V_{ref}+V_{off}$. Accordingly, the output V_2 of the voltage comparison circuit A2 goes high, thereby turning on the current source I1, which provides the compensation current I_c to remove the dc component of the photodiode current I_s from the input node. This

compensation current I_c is preferably equal to the difference between the actual DC component of the present photodiode current I_s and the value of the DC component of the photodiode current I_s corresponding to the minimum feedback resistor voltage V_{r2min} discussed above.

[0026] Referring to Figure 2A, one example of an implementation of the current source I_1 in the circuit of Figure 2 is an N-type metal oxide semiconductor field effect transistor (MOSFET) with its gate terminal driven by the control voltage V_2 and its drain terminal providing the compensation current I_c .

[0027] Referring to Figure 3, a transimpedance amplifier with controllable noise reduction in accordance with an alternative embodiment of the presently claimed invention is similar to the circuit of Figure 2, but receives its photodiode current I_s from a grounded photodiode D_1 and uses the current source I_1 to source rather than sink the compensation current I_c at the input node. Operation of this circuit is in conformance with that discussed above for the circuit of Figure 2.

[0028] Referring to Figure 3, one example implementation of the current source I_1 for the circuit of Figure 3 is a P-type MOSFET with its gate terminal driven by the control voltage V_2 and its drain terminal providing the compensation current I_c .

[0029] Referring to Figure 4, the threshold voltage of $V_{ref} + V_{off}$ can be generated using a replica biasing voltage generator as shown. A replica amplifier A_{1r} , which is designed to be a replica of the amplifier A_1 (Figures 2 and 3) has its differential input terminals both connected to the circuit reference terminal V_{SS}/GND so as to replicate a zero input signal condition. Similarly, a replica feedback resistor R_{2r} is connected to the input $3r$ and output $5r$ terminals. The resulting output voltage V_{ref} is then summed with the offset voltage V_{off}

(which can be generated in virtually any manner) to produce the threshold voltage of $V_{ref} + V_{off}$. The isolation resistors R3, R4 merely provide isolation between the sources of the two voltage components V_{ref} , V_{off} and the voltage comparison circuit A2 (Figures 2 and 3).

[0030] Various other modifications and alternations in the structure and method of operation of this invention will be apparent to those skilled in the art without departing from the scope and the spirit of the invention. Although the invention has been described in connection with specific preferred embodiments, it should be understood that the invention as claimed should not be unduly limited to such specific embodiments. It is intended that the following claims define the scope of the present invention and that structures and methods within the scope of these claims and their equivalents be covered thereby.